SHOCK RESPONSE SPECTRUM TESTING WITH SHOCK MACHINE

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Abstract: Transient mechanical shocks cause dynamic stress in structures which results in defect or malfunction of exposed devices. A shock response spectrum (SRS) is used for characterizing an acceleration response of linear single degree of freedom system to these shocks. This paper is focused on presentation of the shock response spectrum derived from half-sine shock generated by shock machine.

Keywords: Mechanical shock, shock response spectrum

1 INTRODUCTION

Proper function of machines, devices or structures may be affected by mechanical shocks. Depending on operating environment, shock differs in form, amplitude and duration. Typical forms of shocks are represented by half-sine shocks, trapezoidal shocks, earthquake shocks, pyro or naval shocks. Since this paper is focused on shocks generated by shock machine, we will discuss a half-sine form of shock only.

A number of applications, such as aerospace industry, transportation, vehicle components, electronic equipment and many others have to deal with transitory dynamic stress in structures, which is induced by mechanical shock. Magnitude of this stress is a function of the characteristics of the shock and dynamic properties of the structure[1]. A shock can be represented in the time domain or in the frequency domain. For the first case, a shock is fully characterized by three parameters: form, amplitude, and duration [2]. In the frequency domain, a shock response spectrum is commonly used for representing a time-history record of an acceleration. A shock response spectrum characterizes the acceleration response of a single degree of freedom (SDOF) system at a given frequency to a transient shock acceleration input. This SDOF system can be represented as a series of masses connected to the solid base through defined stiffness and damping [3], as schematically illustrates Figure ***1***.

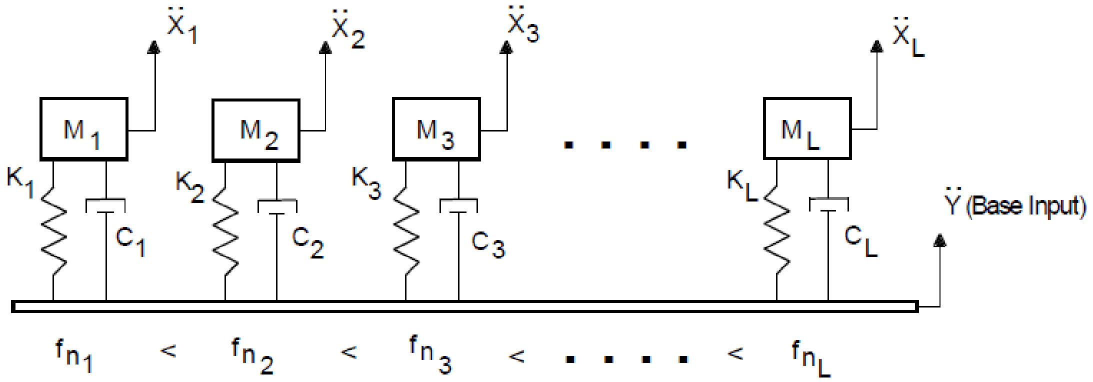

Figure 1: Model of shock response spectrum [3]

$\ddot{X_i}$ is the acceleration response of each system to the common input $\ddot{Y_i}$. M_i, K_i and C_i is the mass, stiffness and damping, respectively.

A shock response spectrum is primary useful in aerospace industry. Since universe is a harsh environment with plenty of impacts inducing sudden acceleration of high amplitudes with short duration, the higher frequency band of a SRS is crucial. For instance, the analysis of shock response spectrum let engineers to design avionics to survive mechanical shocks arising from jet engine ignition or satellite launching process. On the other hand, the lower frequency band of the SRS is useful when testing endurance to seismic excitation. Also, the shock response spectrum can be used as a powerful tool for characterizing transportation environment (packaging material, etc.). This point is important in case of equipment particularly susceptible to shock because inappropriate handling can result in a damage [3]. There are several of other applications employing shock response spectrum, such as reproducing of shipboard naval shocks, in the field of electronic components or automotive [4].

As mentioned above, this paper focuses on half-sine shocks. Testing with half-sine is frequently employed in automotive industry for vehicle components such as oil level sensors, differential pressure sensors for a DPF or fuel supply modules. Figure 2 shows ideal half-sine shock with duration of 11 milliseconds and amplitude of 50 G. Corresponding shock response spectrum is shown in Figure 3. There are three highlighted points at 30 Hz, 80 Hz and 140 Hz. These points show acceleration response of SDOF system at a given independent natural frequency with Q factor of 10. Hence, natural frequency of 30 Hz will generate 55 G for the case with Q = 10 of SDOF system as a response to the half-sine shock. Similarly, this response is represented by every single point of the curve of a shock response spectrum. It can be noted, that Q = 10 corresponds to damping coefficient of 5 % [3].

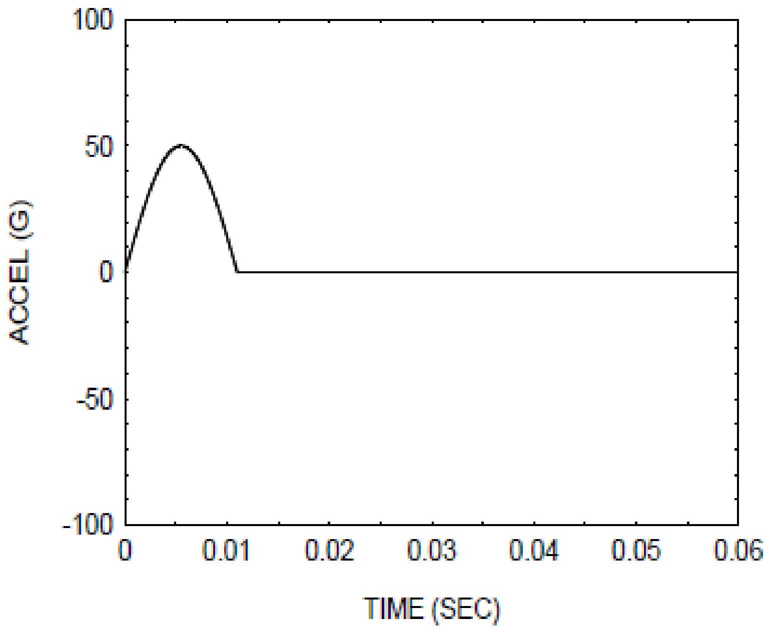

Figure 2: Ideal half-sine shock of 50 G and 11 milliseconds [3]

Resulting shock response spectrum depends on time-history of the input acceleration. For one mechanical shock is possible to obtain several different shock response spectra. We distinguish shock response spectra into five types. The first is referred to as *maximax*. In this case, the spectrum represents the maximum absolute response over the entire duration (excitation and residual). Secondly, the *maximum positive* spectrum, which corresponds to the maximum positive response over the entire duration and similarly the *maximum negative* spectrum. The *primary spectrum* is constructed from the maximum absolute response during the excitation and the *residual spectrum* interprets peak response after the excitation [5].

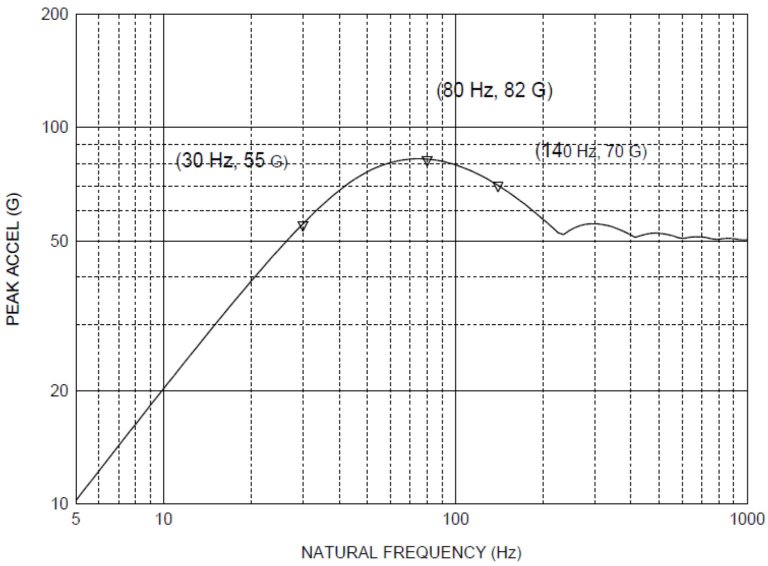

Figure 3: Maximax shock response spectrum transformed from ideal half-sine 50 G and 11 ms [3]

2 SHOCK RESPONSE SPECTRUM IN ACCORDANCE WITH EN 60068-2-81

Standard EN 60068-2-81 describes tests employing a shock response spectrum. The main aim of this type of test is to synthetize an appropriate acceleration time history due to specified shock response spectrum. This can be done by several methods, such as superimposing of sine waves with different amplitudes and frequencies in certain time window or damped sine function over limited time. The resulting shock response spectrum should be in ±1.5 dB from requested spectrum [6].

Discrepancies between real and created acceleration time history can occur, because there is no unique acceleration time history associated with a given shock response spectrum. So, definition of transient shock in time domain is necessary in order to meet authentic operating conditions. It should be noted, that synthetizing of an acceleration time history is a feature of modern control systems of electrodynamic vibration shakers. However, conventional exciters have some limitations by means of frequency band (typically up to 3000 Hz) and maximum amplitudes (up to 400 G) [6].

Qualifying of space equipment and many other applications need testing in wider frequency band and with higher acceleration amplitudes. Hence, another approach to generate transient shock is necessary. Pyro shock refers to high frequency and high amplitude mechanical excitation, but these tests are very complex and require explosives. As a result, operational cost is high. In some occasions a pyro shock can be substituted by metal to metal impact, which is far simpler and gives similar shock excitation [7].

3 SHOCK MACHINE AS SHOCK EXCITER FOR SRS

Testing laboratory CVVOZE at the Department of Control and Instrumentation, Faculty of Electrical Engineering and Communication, provides vibration, shocks, and climatic tests. The testing equipment for shocks and vibration consists of 24 KN electrodynamic shaker and pneumatic shock machine. Control system for this shaker (SWR1200) does not have an acceleration time history synthetizing function and maximal amplitude of shock is approximately 180 G with unloaded vibrating system. The shock machine Avex SM-110 provides shock testing up to 30 000 G and therefore requirements for higher amplitudes are accomplished. The form of shock depends on impact pad and it could be a half-sine, sawtooth or square wave pulse. Hence, there is also no option to synthetize an acceleration time history in order to reproduce an arbitrary shock response spectrum.

As mentioned above, many engineers deal with a shock of half-sine form in their research. So, the shock machine offering high amplitudes of acceleration is on point. For demonstrating purposes, a shock response spectrum from measured half sine shock excited by the shock machine was obtained. Figure 4 shows time-history of measured half-sine shock with amplitude of approximately 1 400 G and duration of 0.5 milliseconds.

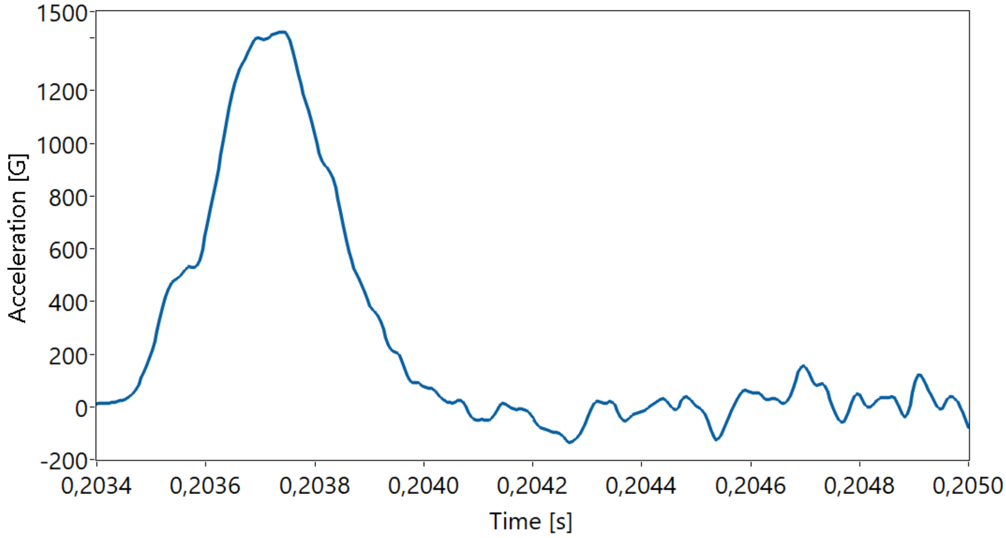

Figure 4: Half-sine shock of 1400 G and 0.5 ms excited by the shock machine

Measurement was performed with NI PXIe-1062Q in cooperation with sound and vibration module NI PXI-4462. The maximax shock response spectrum, in Figure 5, was calculated in LabVIEW program employing Sound and Vibration Measurement Suite toolbox. Measured time-history record of the shock (24-bits at 200 kS/s) is filtered with low-pass 4th order Bessel filter with cutoff frequency of 15 kHz. The cutoff frequency is set in accordance with EN 60068-2-81 and it should be 1.5 times higher than the highest frequency of interest [6] (for this case, SRS was investigated in the frequency range up to 10 kHz).

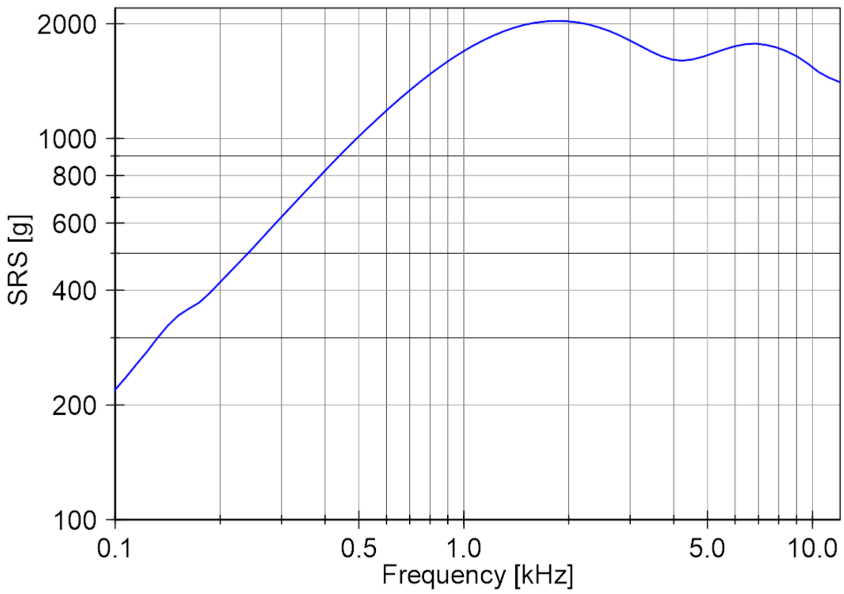

Figure 5: Calculated maximax SRS from measured half-sine shock

4 CONCLUSIONS

This article has only been able to touch on the most general features of the shock response spectrum. Using of the shock machine as an exciter for the transient shocks is straightforward and allows reach high amplitudes in order of thousands G with low operational cost. In Figure 5 was demonstrated a maximax shock response spectrum obtained from the half-sine time history acceleration excited by shock machine Avex SM-110. It can be noted that the shape of measured SRS and ideal SRS is almost identical.

In general, the limiting factor of shock machines is represented by pre-defined shock wave pulses without possibility to generate an arbitrary acceleration time-history. Hence, the shape of provided shock response spectrum cannot be significantly changed.

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